Multipion production

in ***np*** interactions at intermediate energies

A.P. Jerusalimov, *S.G. Arakelian, A.V.Belyaev, V.P.Ladygin, Yu.A. Troyan*

JINR-LHEP, Dubna

Outlook

1. **Introduction**
2. **Experiment**
3. **2π production in np interactions**
4. **3π and 4π production in np interactions**
5. **5π and 6π production in np interactions**
6. **Conclusion**

   Reference

ISHEPP_XXIV Dubna Sept. 17-22, 2018

1. Introduction

Specific interest in NN collisions at intermediate energies is the study of excitation of baryons and their subsequent decays :

$\mathbf{\Delta}_{1232} \rightarrow \mathbf{N}\boldsymbol{\pi}$, $\mathbf{N}^*_{1440} \rightarrow \mathbf{\Delta}\boldsymbol{\pi}$, $\mathbf{N}^*_{1440} \rightarrow \mathbf{N}\boldsymbol{\sigma}$, $\mathbf{N}^*_{1440} \rightarrow \mathbf{N}\boldsymbol{\rho}$,

ΔΔ-production.

Multi pion production in NN collisions is one way to obtain information about the **NN**, ***π*N** and ***ππ*** states, including:

dibaryons (including I=2 in $pp\pi^+$),

dipions (narrow ***σ***-meson, state with **I=2**),

pentaquarks (I=5/2, S=+1).

missing resonances etc.

Important task is the test of the models of pions production in NN-interaction:

- **Valencia** model[10]
- **Xu Cao** model[11]
- **(OPER+OBE)** model[3-6,7]

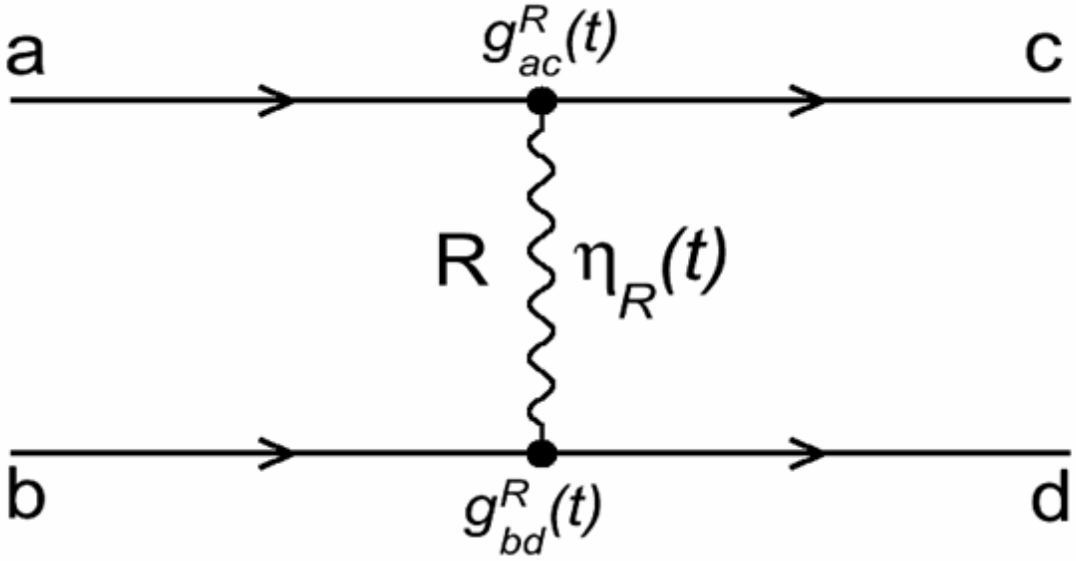
Various modifications of the one pion exchange models (OPE) are used to describe the experimental data of the inelastic NN-, NbarN- and πN-interactions. At that parameters of these models are different for various processes and even for concrete reactions at various energies.

Various models differ also in respect of the reggeization of π-meson: at times an exchange by elementary π-meson [1] is used at other times - by reggeized π-meson [2]. The models of Regge pole exchange [3,4] are based on the **method of complex momenta** and consider an exchange in t-channel by a virtual state **R** that has quantum numbers of particle (resonances) with variable spin and is on some trajectory $\alpha_R(t)$ named Regge trajectory.

The most developed and detailed model of reggeized π -meson exchange is the model suggested in ITEP [5]. The advantages of this model are:

- small number of free parameters (3 in our case),
- wide region of the described energies (2 ÷ 200 GeV),
- calculated values are automatically normalized to the reaction cross-section.

Amplitude of binary and quasi-binary processes **a + b → c + d** [3]



$$T_R(s,t) = i8\pi s_0\, g^R_{ac}(t)\, \eta_R(t) \left(\frac{ss_0}{m_c^2 m_d^2}\right)^{\alpha_R(t)} g^R_{bd}(t)$$

where $g^R_{ac}(t)$, $g^R_{bd}(t)$ – vertex functions

$\alpha_R(t)$ - Regge trajectory

$$\eta_R(t) = -\frac{\sigma + \exp(-i\pi\alpha_R(t))}{\sin[\pi\alpha_R(t)]}$$

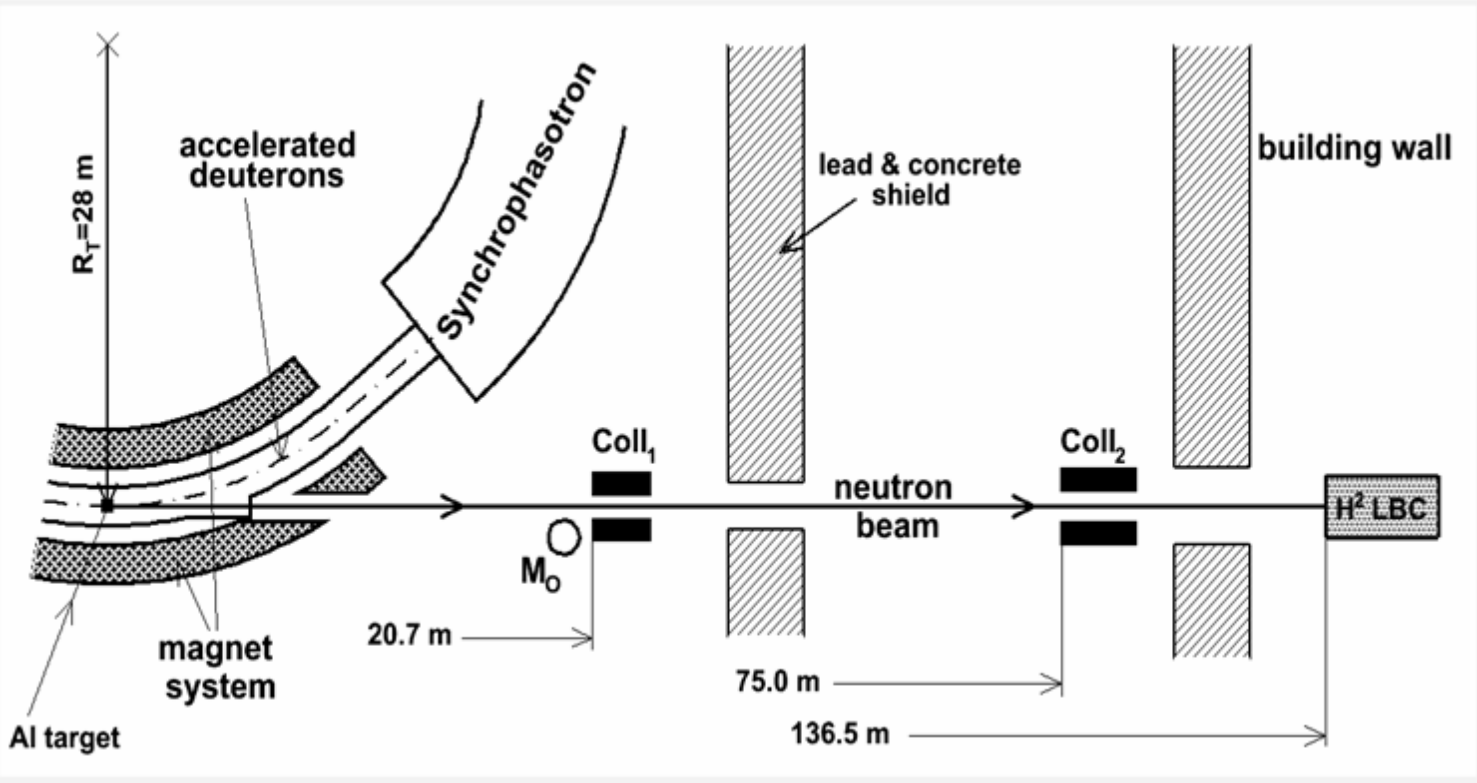
- signature factor with signature

$\sigma = (-1)^l$ for interger l (bosons)

$\sigma = (-1)^{l\pm 1/2}$ for interger l (fermions)

2. **Experiment:** study of inelastic np interactions

at accelerator facility of LHEP JINR

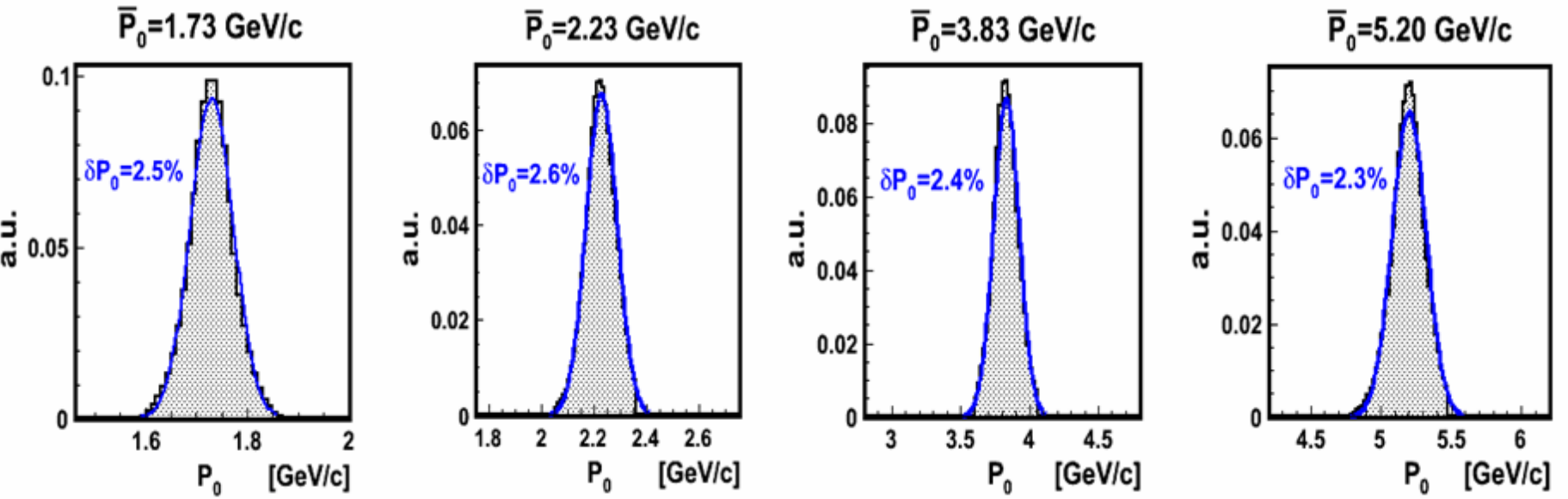


The unique of fullness and precision data are obtained.

It permits to carry out the detailed study of inelastic np interactions in a wide region of energies

- **Quasimonochromatic neutron channel: δP≈2.5% ,**

P_0=1.73, 2.23, 3.83, 4.42 and 5.20 GeV/c,
4π geometry.



The reactions with from 2 up to 6 **π** -mesons in the final states were studied at these momenta
The separation of the reaction were carried out by the standard **χ^2-procedure**

The study of π-meson production in np-interactions are carried out in LHEP JINR.

The following reactions are investigated in Dubna:

- **$np \rightarrow np$ (pn)**
- **$np \rightarrow pp\pi^-$**
- **$np \rightarrow pp\pi^- \pi^0$**
- **$np \rightarrow np\ \pi^+ \pi^-$**
- **$np \rightarrow d\ \pi^+ \pi^-$ (ABC and DEF effects were observed)**
- **$np \rightarrow pp\ \pi^+ \pi^- \pi^-$**
- **$np \rightarrow pp\ \pi^+ \pi^- \pi^- \pi^0$ (η^0 and ω^0 were observed)**
- **$np \rightarrow np\ \pi^+ \pi^+ \pi^- \pi^-$**
- **$np \rightarrow pp\ \pi^+ \pi^+ \pi^- \pi^- \pi^-$**
- **$np \rightarrow pp\ \pi^+ \pi^+ \pi^- \pi^- \pi^- \pi^0$ (**statistics is small**)**
- **$np \rightarrow np\ \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^-$ (**statistics is small**)**

using H^2 target and pure neutron beam ($\delta P_n \approx 2.5\%$).

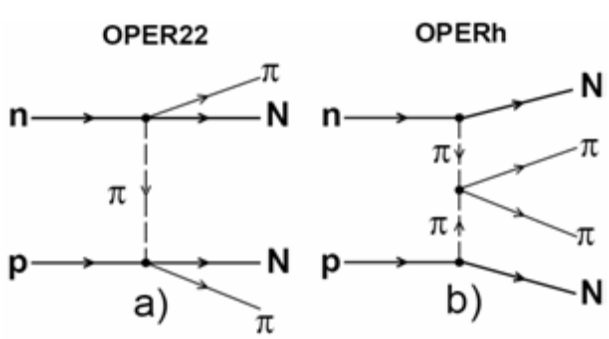
The detailed investigations are carried out at P_0=1.25, 1.43, 1.73, 2.23, 3.83 ,4.42 and 5.20 GeV/c.

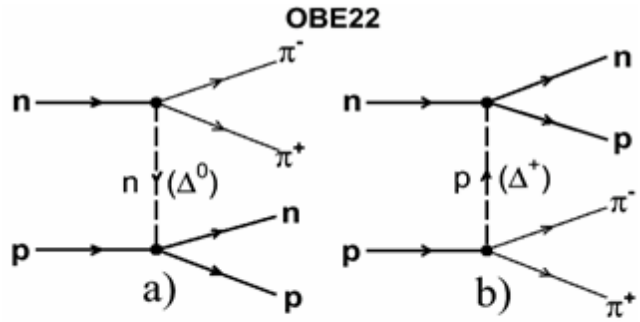
3. 2π production in NN interactions

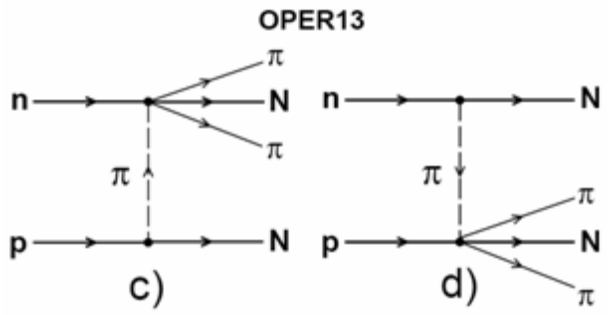
Reaction

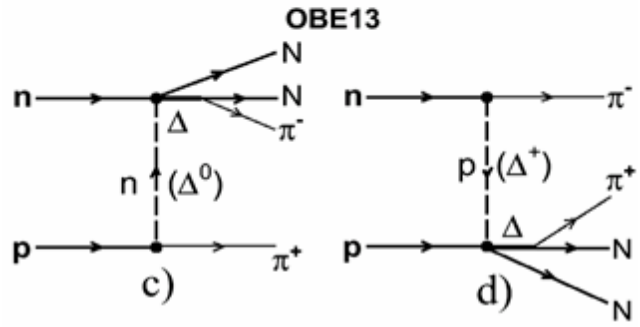
$np \rightarrow np\pi^+\pi^-$

Diagrams: →



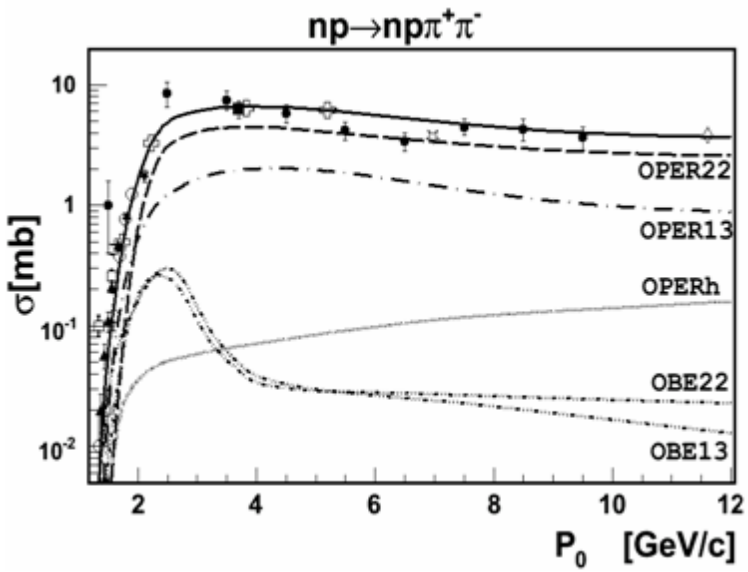


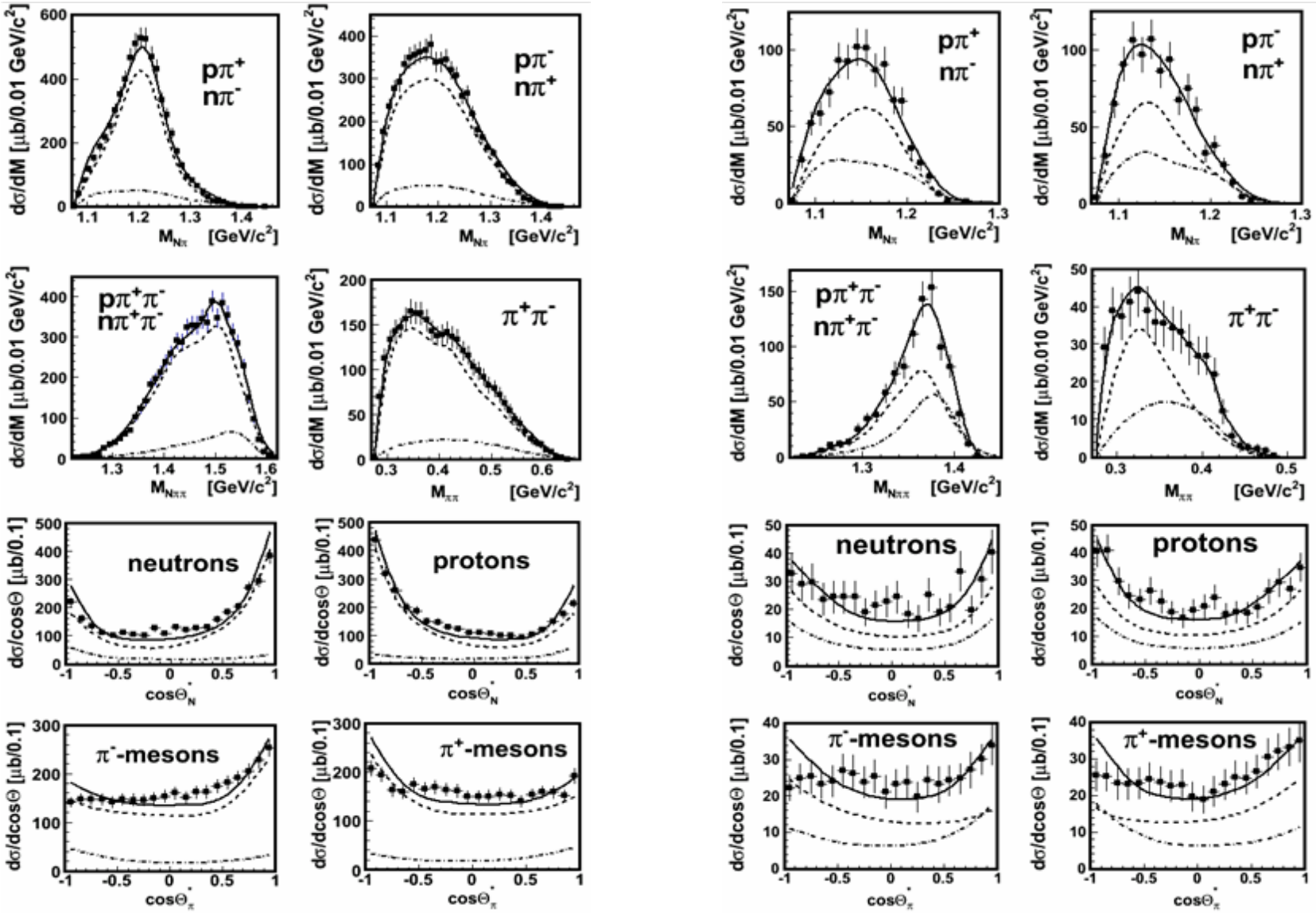




Cross-sections
and contributions (in %)
of diagrams

P_0(GeV/c)	1.73	2.23	3.83	5.20
σ(mb)	0.50 ± 0.04	3.30 ± 0.18	6.46 ± 0.32	6.22 ± 0.28
OPER22	14.2	55.5	67.6	65.4
OPER13	45.3	27.6	30.2	32.4
OPERh	4.9	1.3	0.9	1.4
OBE22	23.3	8.0	0.6	0.4
OBE13	14.2	7.9	0.7	0.5

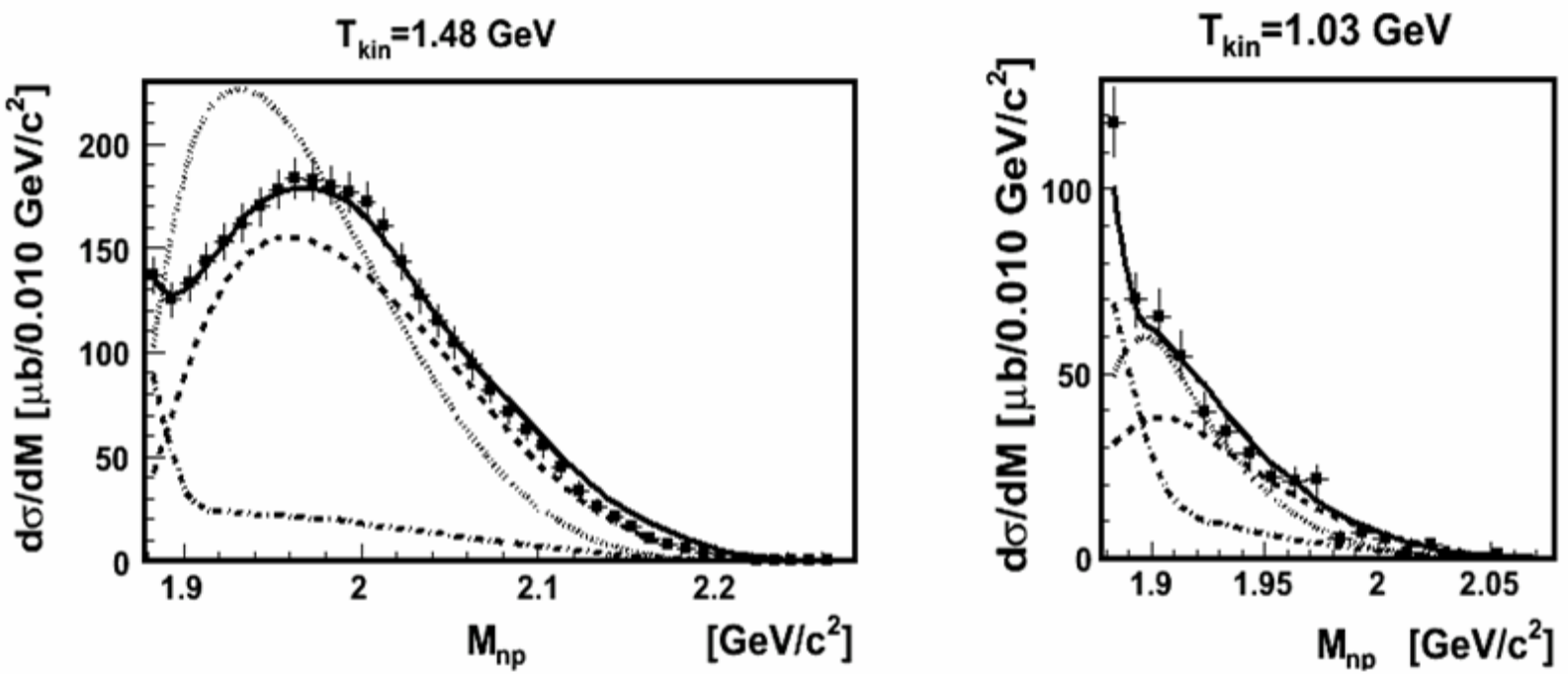




Distributions for the reaction ***np → npπ⁺π⁻***

at P_0=2.23 GeV/c (T_{kin}=1.48 GeV, left) and at P_0=1.73 GeV/c (T_{kin}=1.03 GeV, right)

[*A.P.Jerusalimov et al.,* ***Eur.Phys.J. A51 (2015) no.7, 83***]



Distributions for the reaction ***np → npπ⁺π⁻***
at P_0=2.23 GeV/c (T_{kin}=1.48 GeV, left) and at P_0=1.73 GeV/c (T_{kin}=1.03 GeV, right)

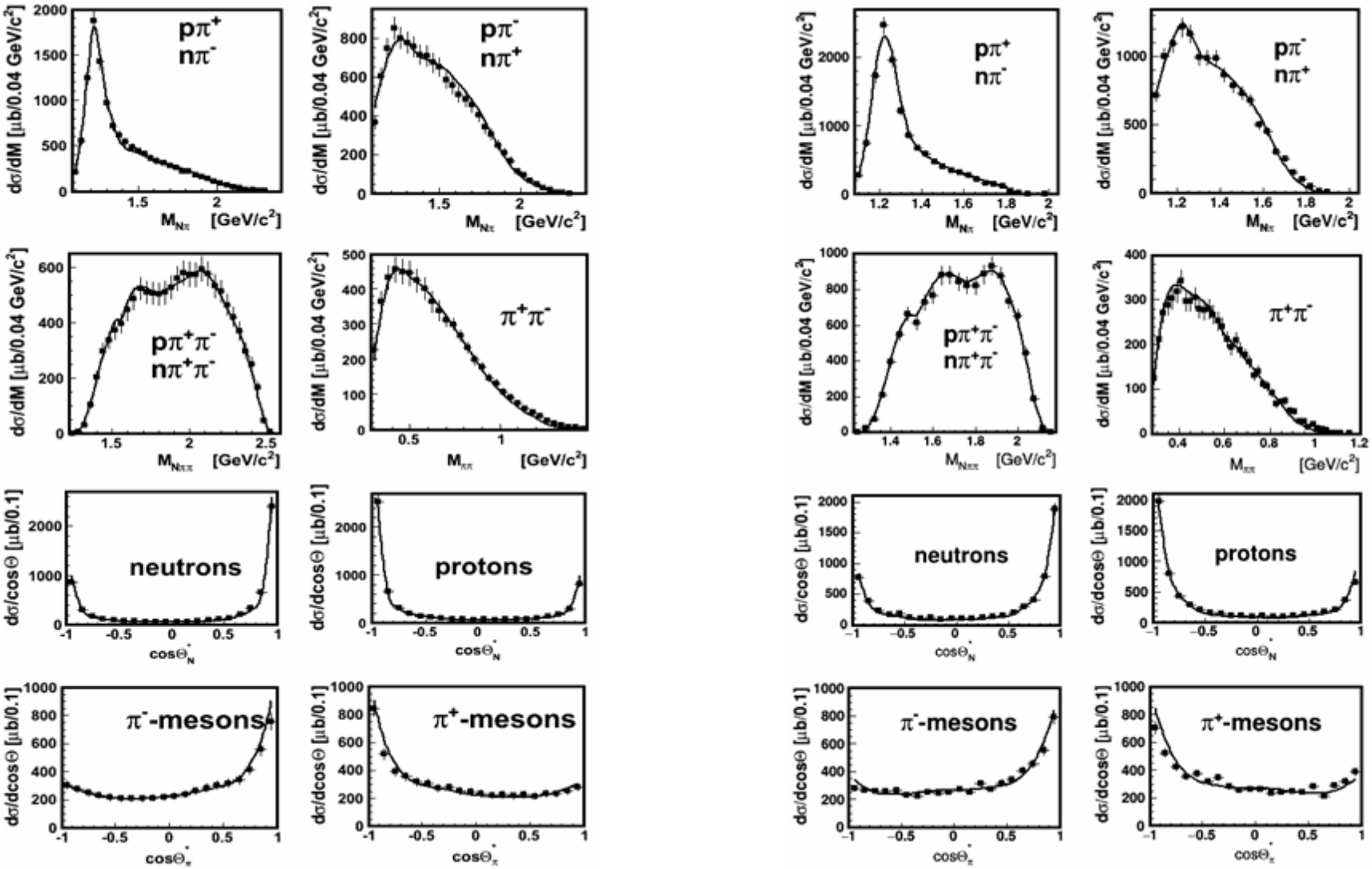
——— Total (OPER + OBE)

– – – – – – OPER

– · – · – · – OBE

····· Valencia model (normalization by factor 2.5 for T_{kin}=1.0 GeV and 1.9 for T_{kin}=1.5 GeV)

[*A.P.Jerusalimov et al.*, ***Eur.Phys.J. A51 (2015) no.7, 83***]

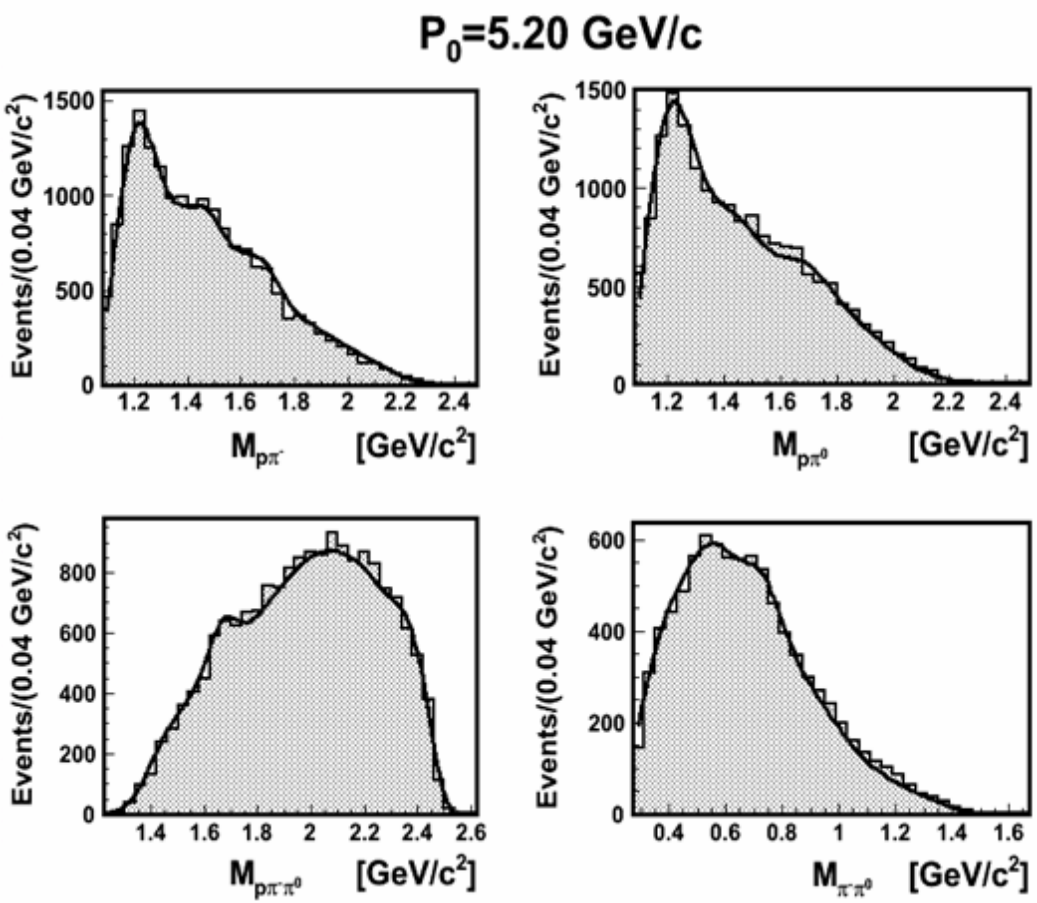


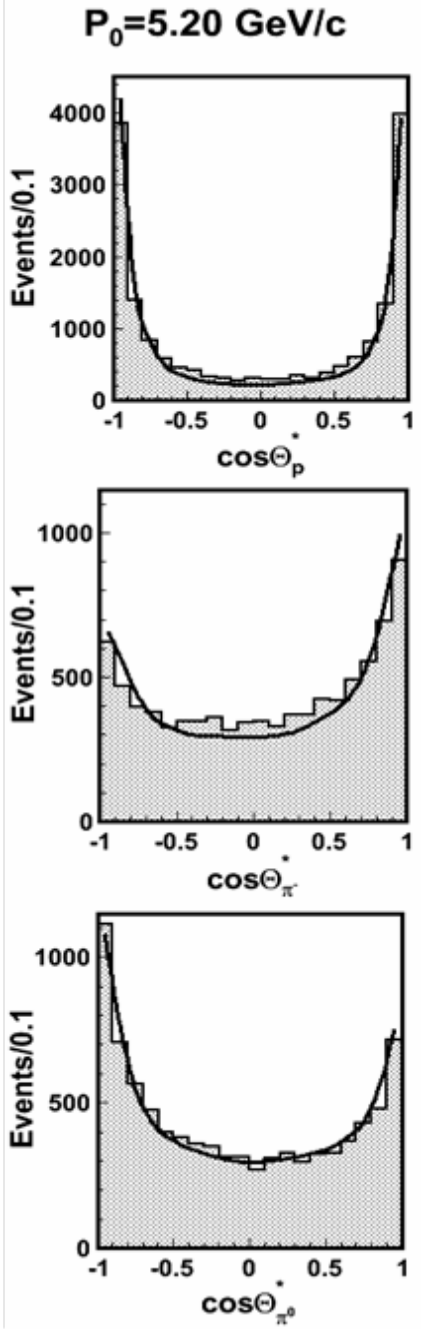
Distributions for the reaction ***np → npπ⁺π⁻***
at P_0=5.20 GeV/c (T_{kin}=4.35 GeV, left) and at P_0=3.83 GeV/c (T_{kin}=3.0 GeV, left)

Mass and **angular** spectra of the reaction

np → ppπ⁻ π⁰

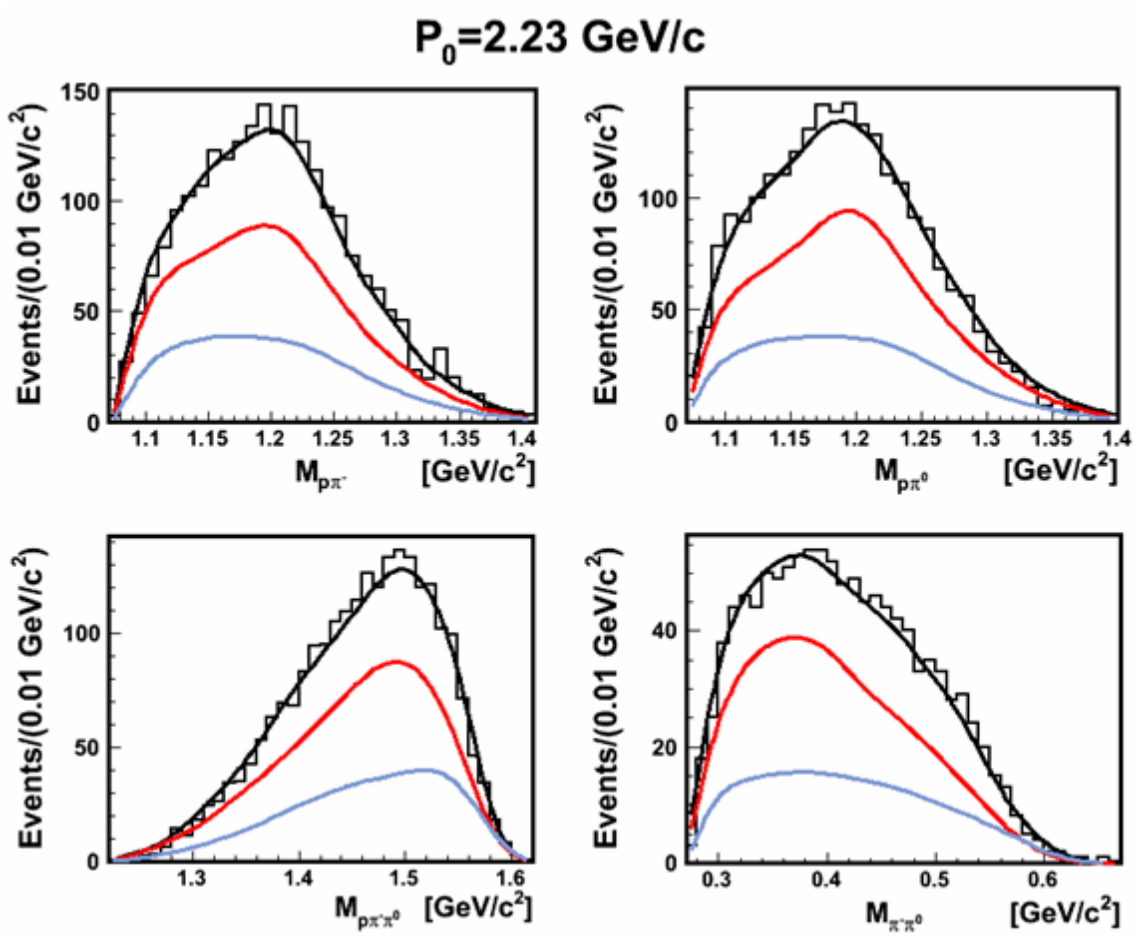
at P_0=5.20 GeV/c (T_{kin}=4.35 GeV)

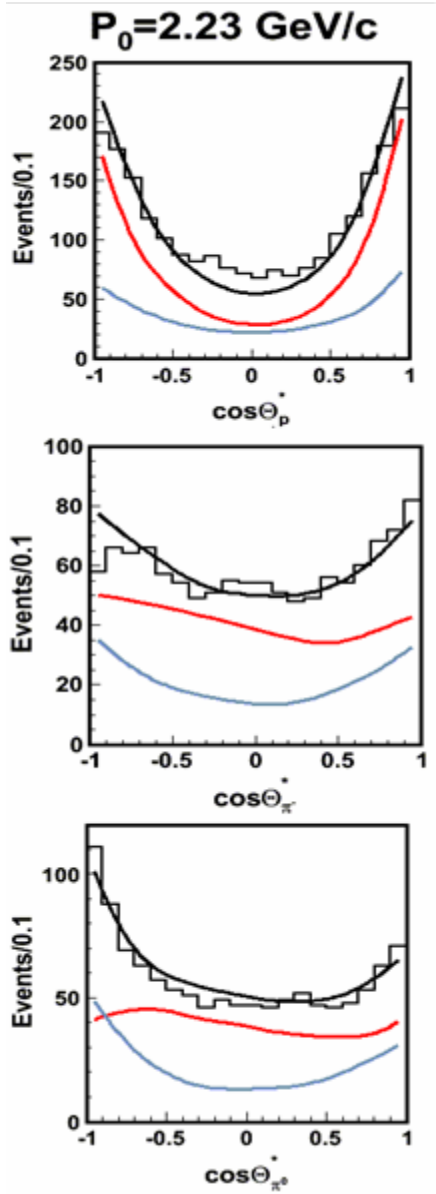




Mass and **angular** spectra of the reaction

$np \rightarrow pp\pi^- \pi^0$ at P_0=2.23 GeV/c (T_{kin}=1.48 GeV)



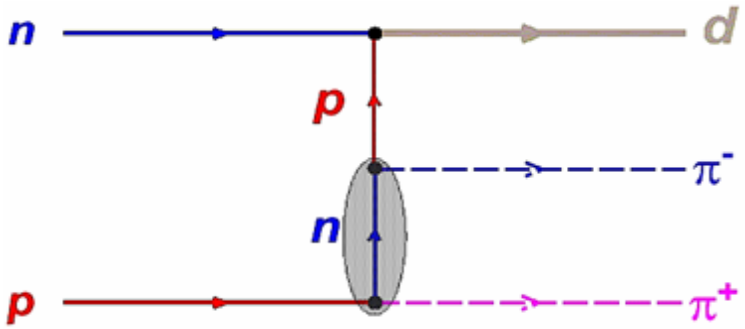


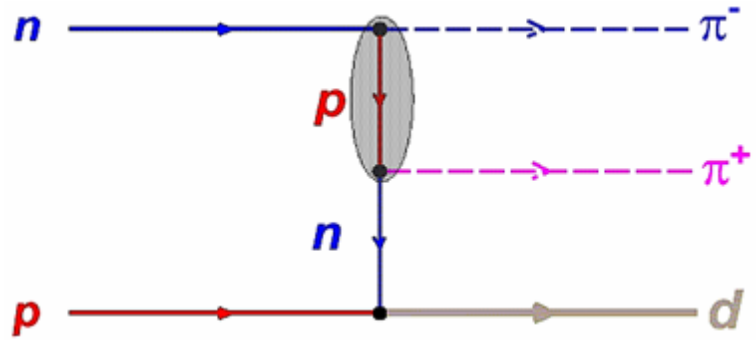
- **Total**
- **OPER**
- **OBE**

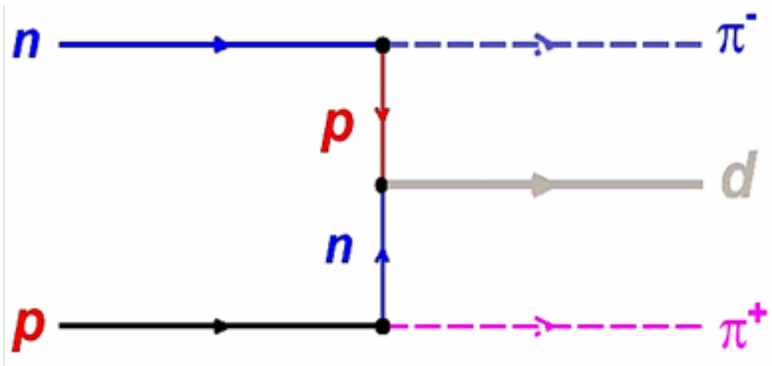
Reaction $np \to np \to d\pi^+ \pi^-$

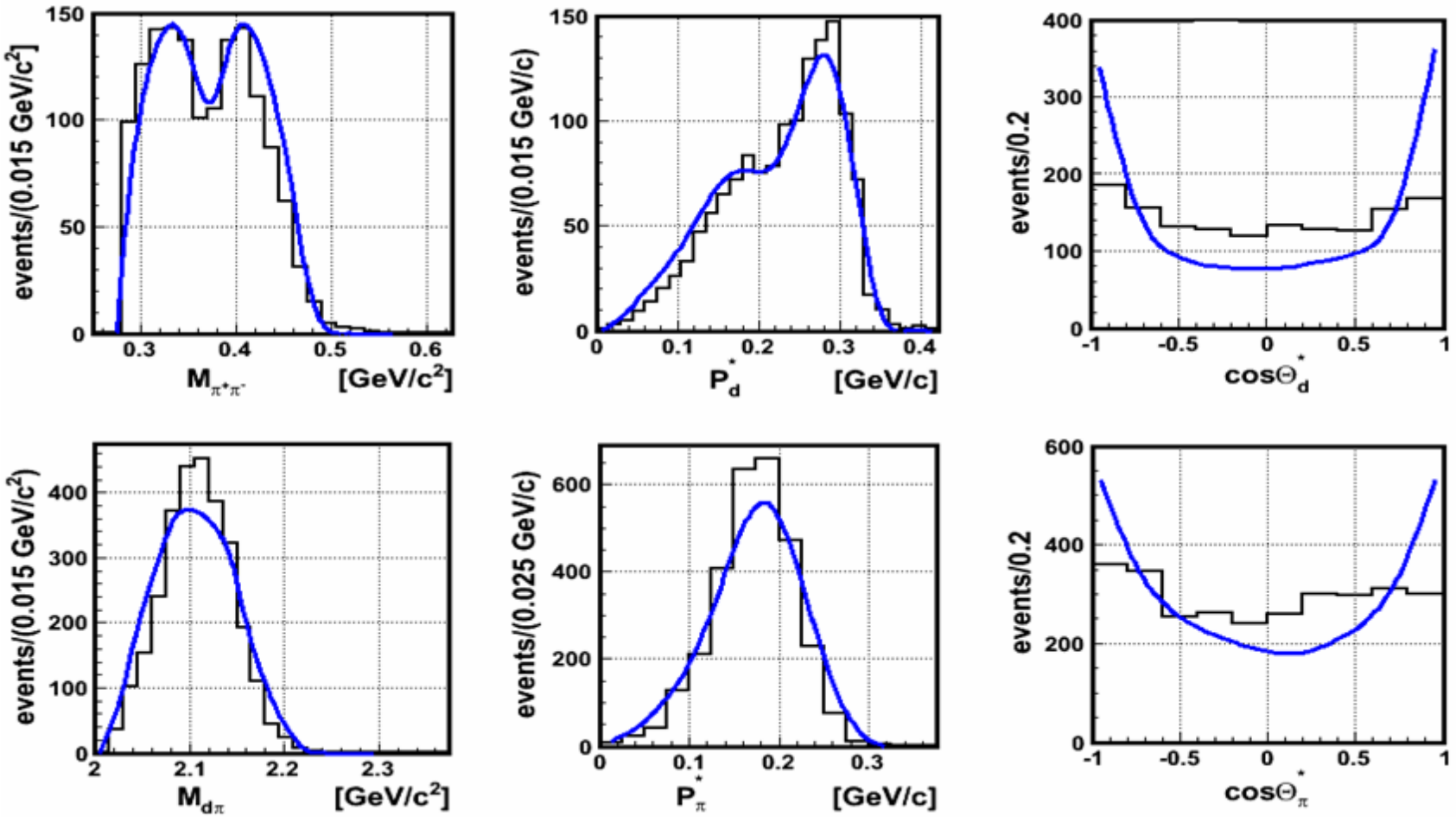
The experimental results at P_0=1.73 and 2.23 GeV/c were published in
[*A.Abdivaliev et al*. **NP B168** (1980), pp.385-393]

It seems to be reasonable to take into account the following **OBE diagrams** to describe the data:





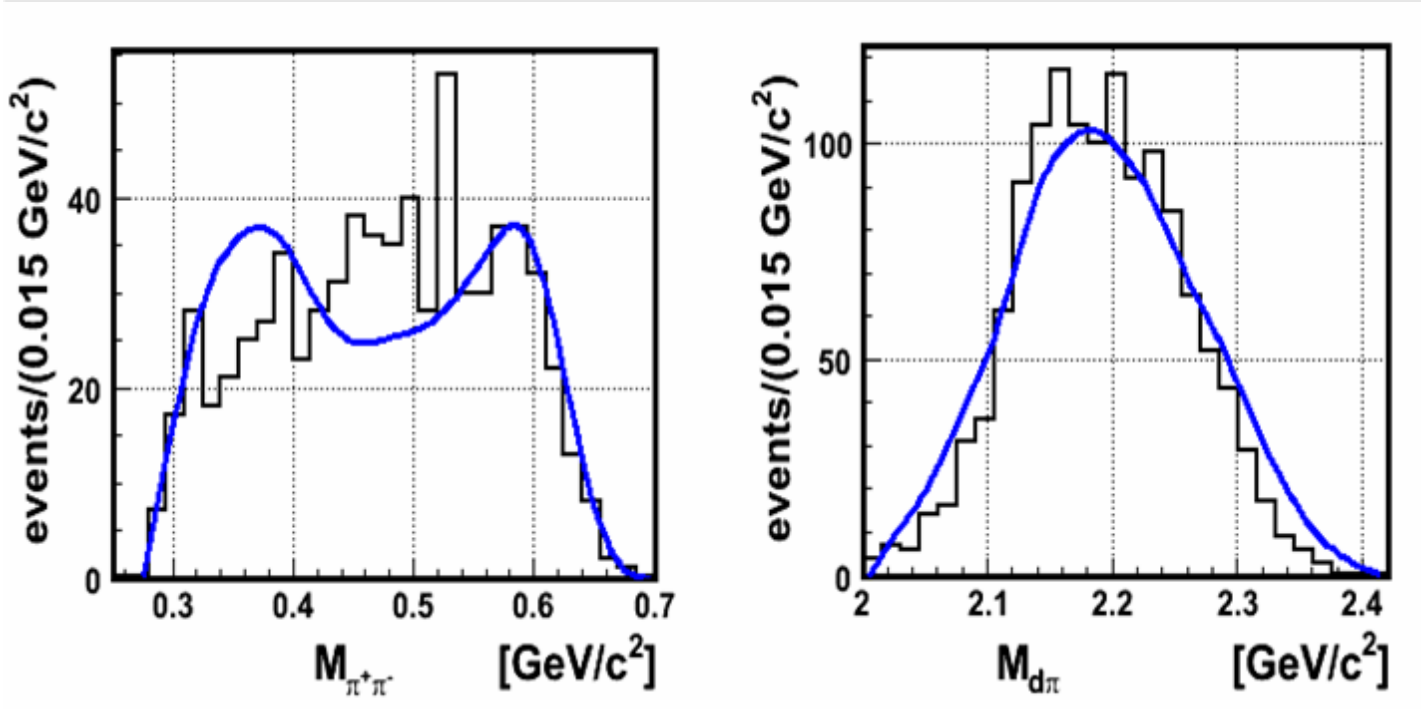




The distributions for the reaction $np \rightarrow d\,\pi^+\,\pi^-$ at P_0=1.73 GeV/c.

Solid line – calculations using OBE-model.

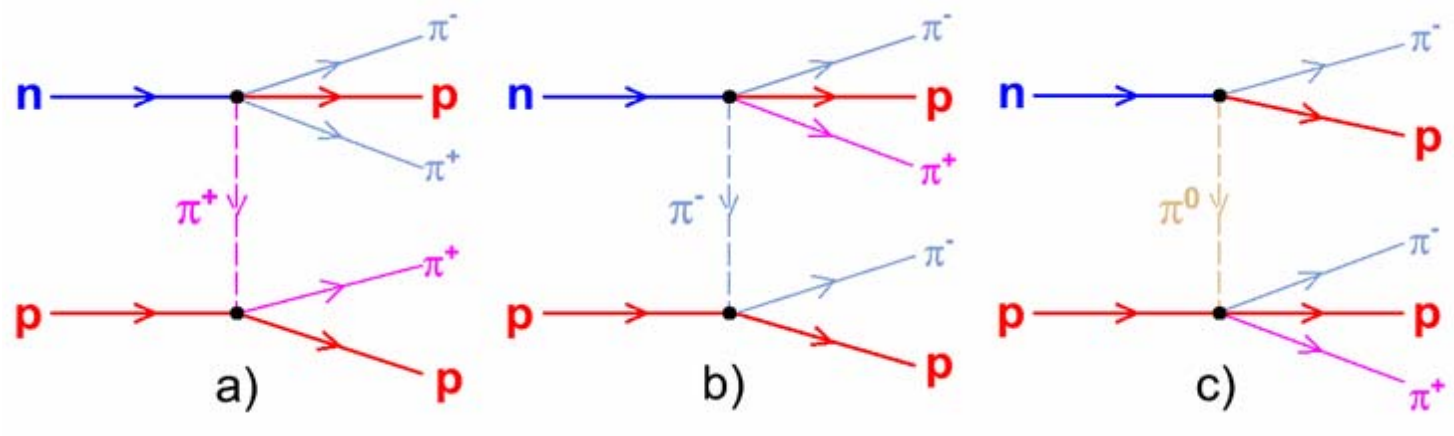
One can see ABC and DEF bumps in 2π mass spectrum.



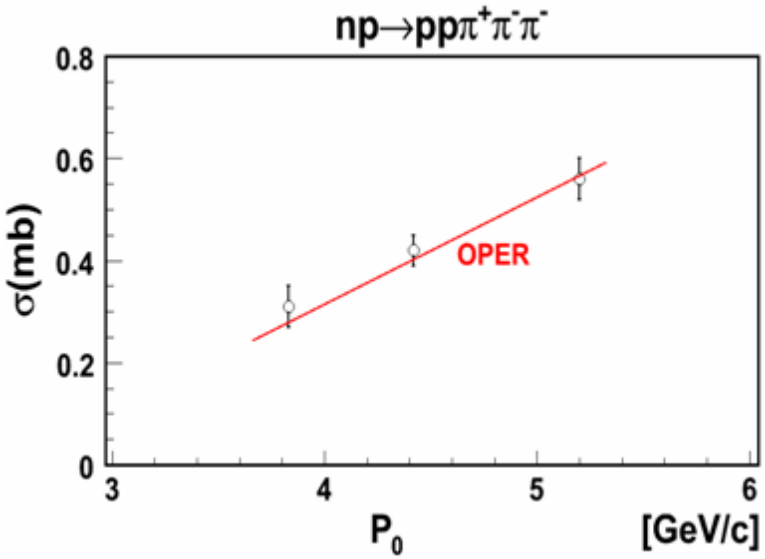
The distributions for the reaction $np \rightarrow d\,\pi^+\,\pi^-$ at P_0=2.23 GeV/c.
Solid line – calculations using OBE-model.

4. 3π and 4π production in np interactions

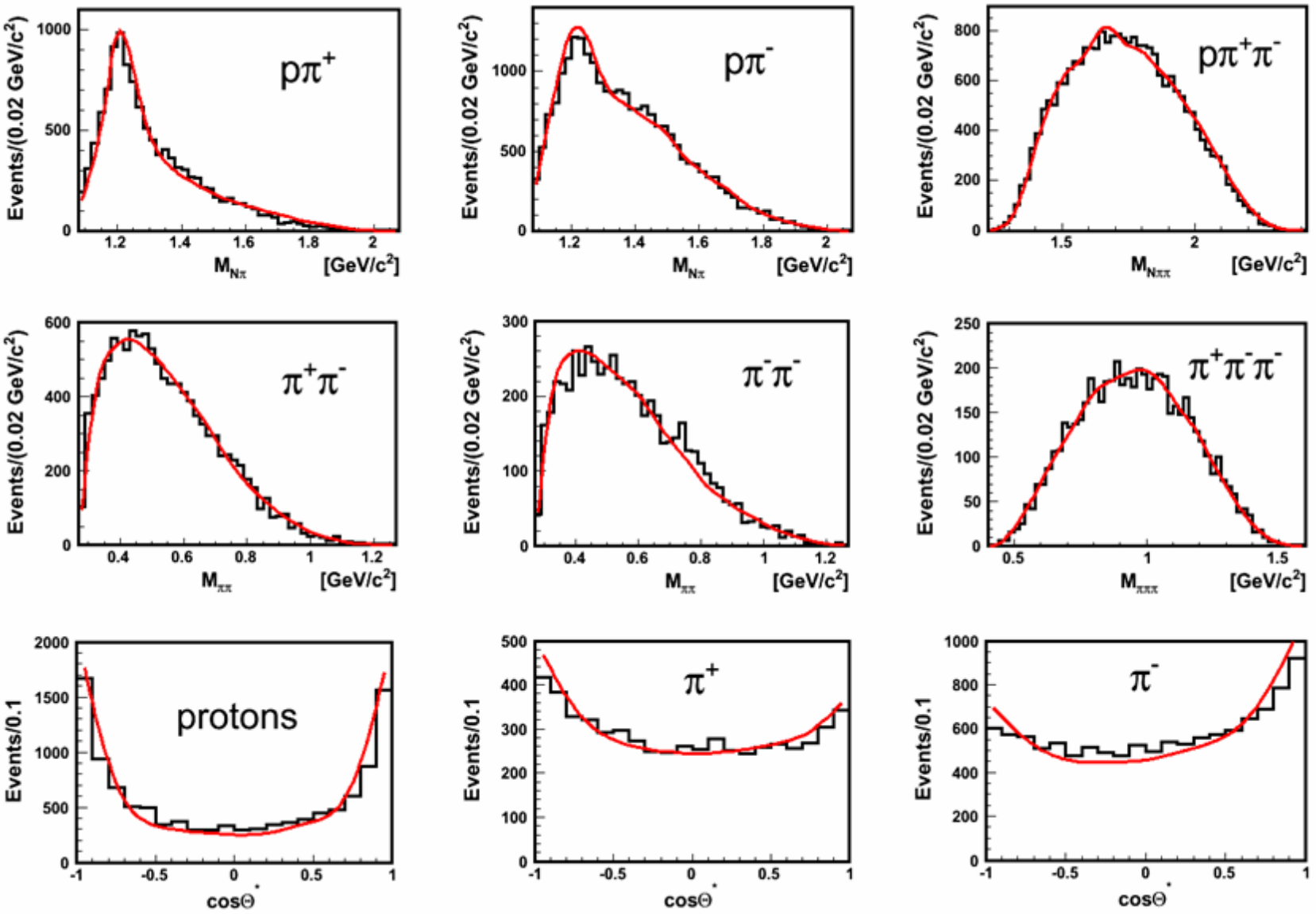
- **Reaction** $np \to pp\pi^+\pi^-\pi^-$



$$M_{32} = T^{up}_{\pi N\to\pi\pi N}\,\frac{F_{32}(s,t,s_{p\pi\pi},s_{p\pi},\ldots)}{(t-m_\pi^2)}\,T^{down}_{\pi N\to\pi N} \longrightarrow$$

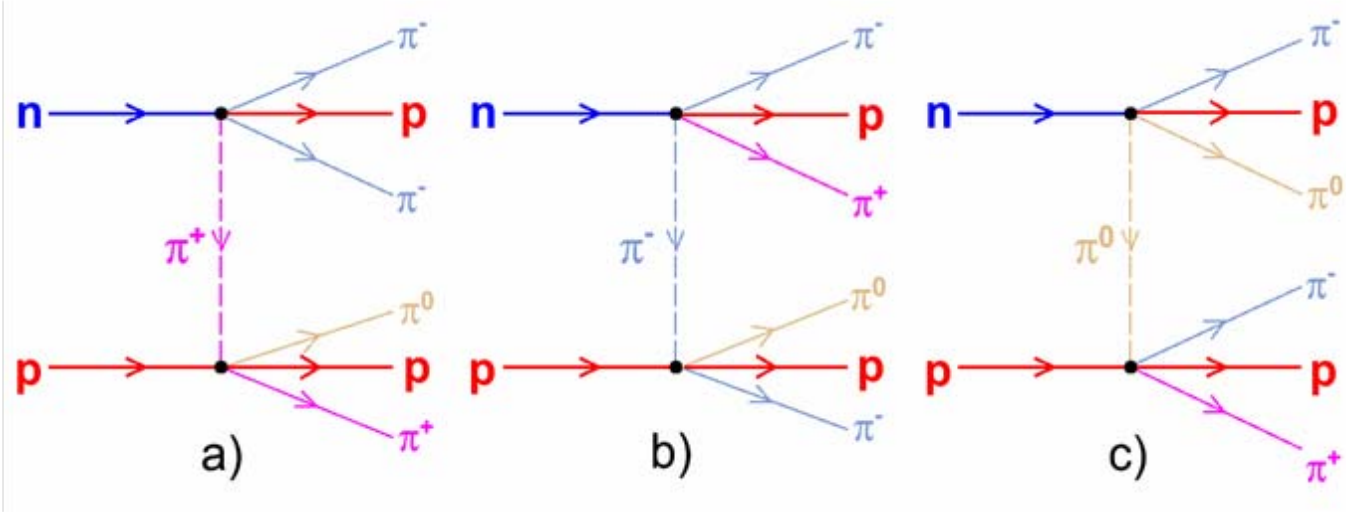


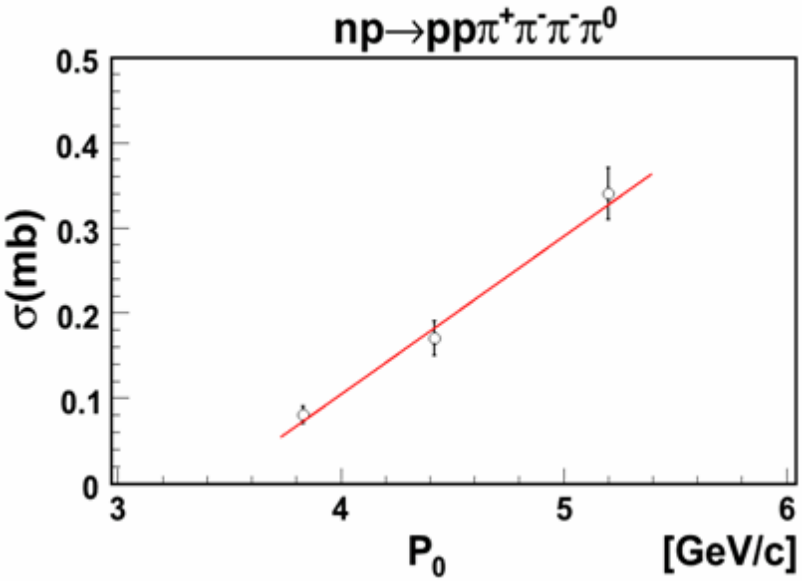
Cross-section of the reaction $np \to pp\pi^+\pi^-\pi^-$ vs momentum of incident beam.



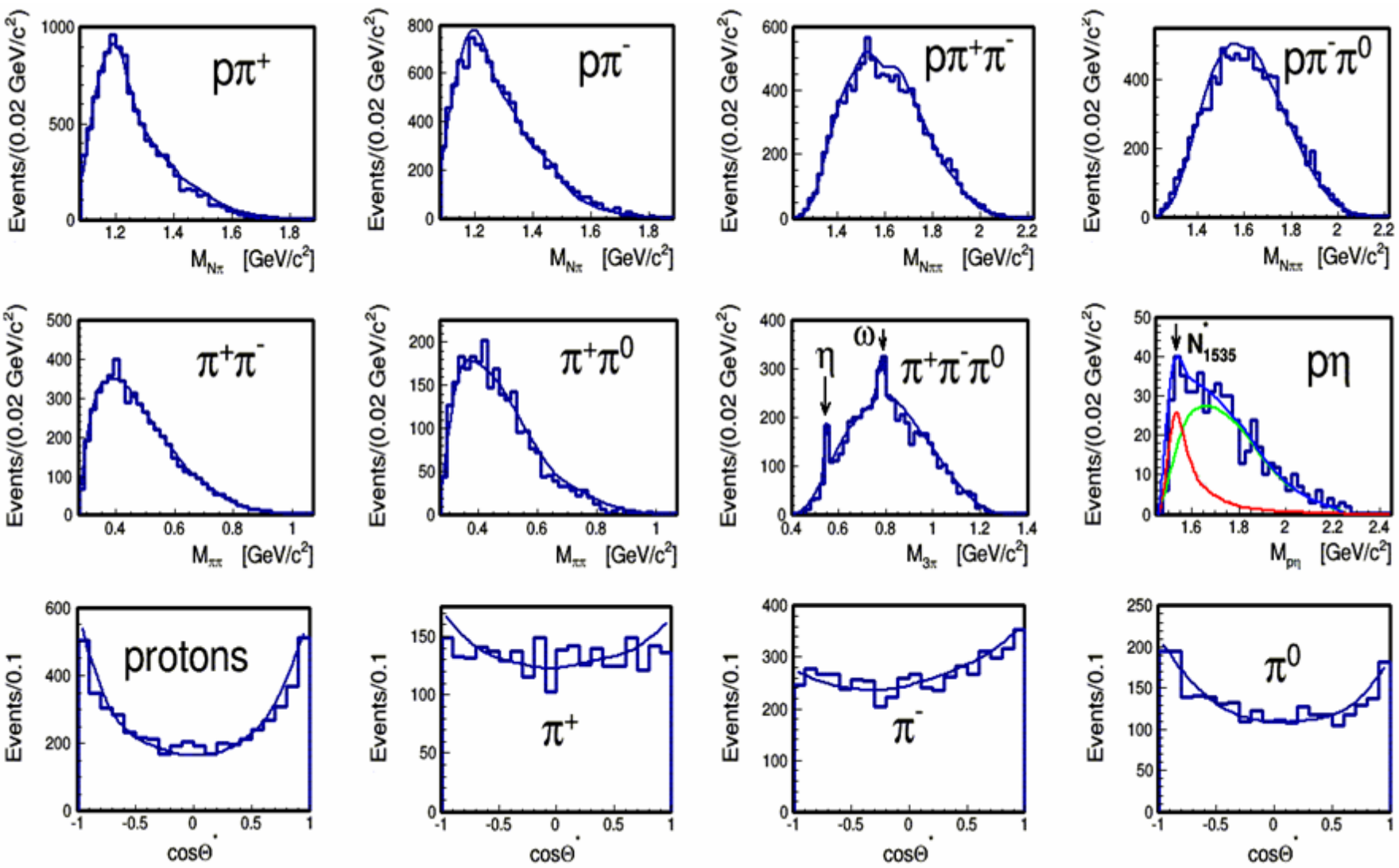
The distributions for the reaction $np \rightarrow pp\pi^+\pi^-\pi^-$ at P_0=5.20 GeV/c.
Red line – calculations using OPER-model.

- **Reaction** $np \rightarrow pp\pi^+\pi^-\pi^-\pi^0$

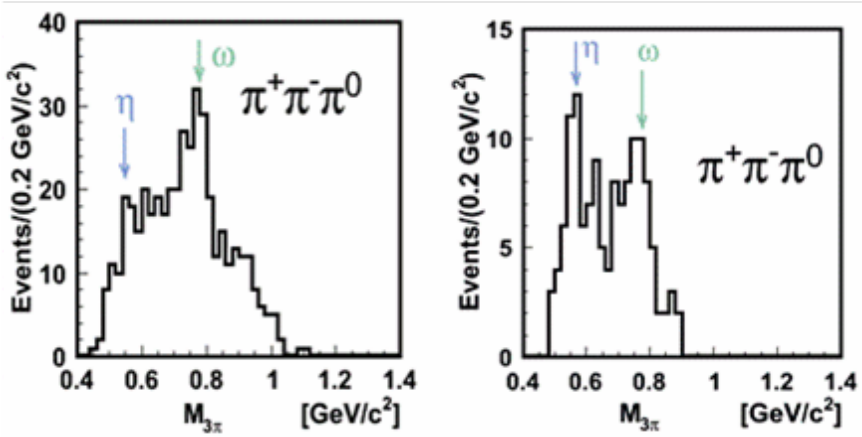




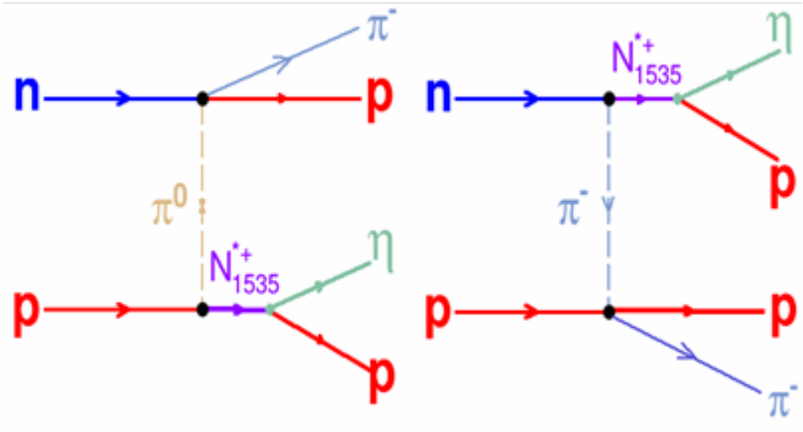
Cross-section of the reaction $np \rightarrow pp\pi^+\pi^-\pi^-\pi^0$ **vs momentum of incident beam.**

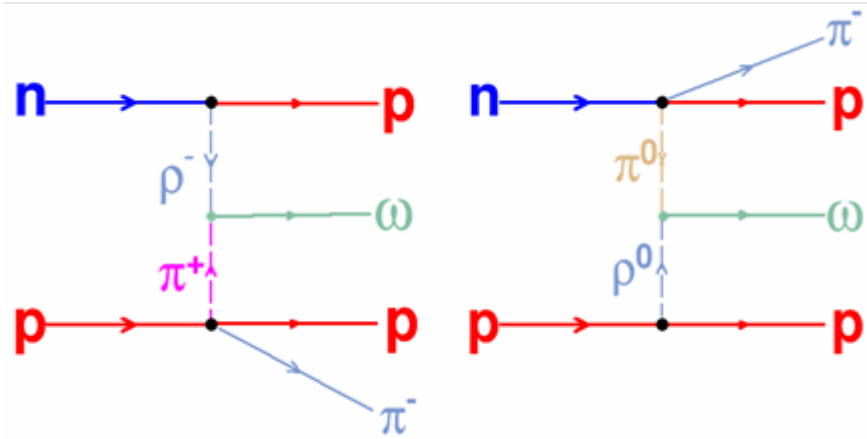


The distributions for the reaction $np \rightarrow pp\pi^+\pi^-\pi^-\pi^0$ at P_0=5.20 GeV/c. Solid line – calculations using OPER-model.



The distributions of $M_{\pi^+\pi^-\pi^0}$ for the reaction $np \to pp\pi^+\pi^-\pi^-\pi^0$ at P_0=4.42 GeV/c (left panel) and at P_0=3.83 GeV/c (right panel).

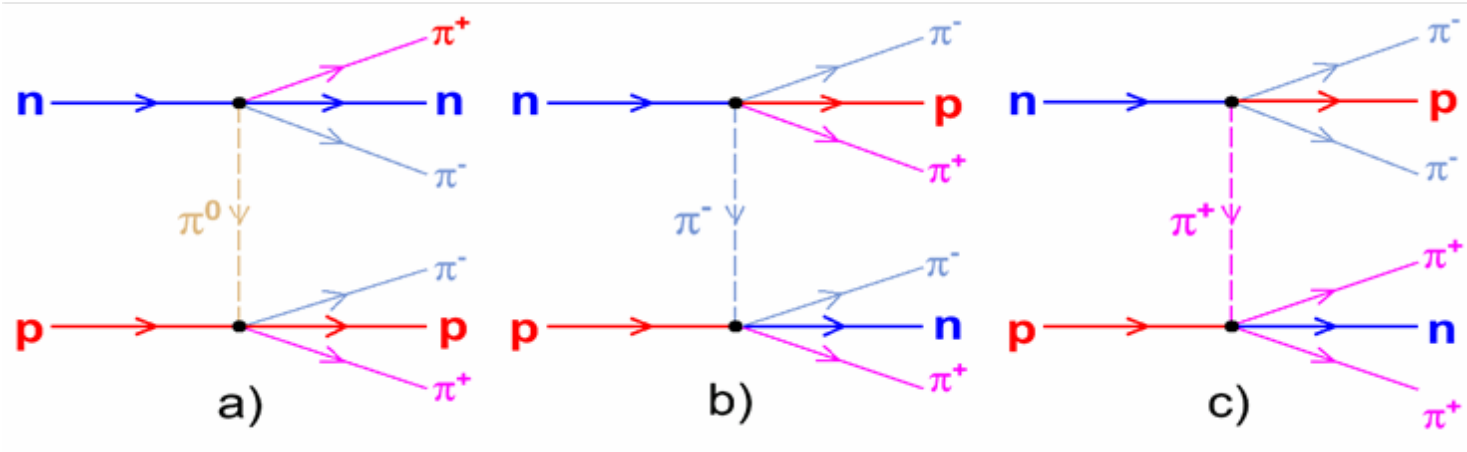


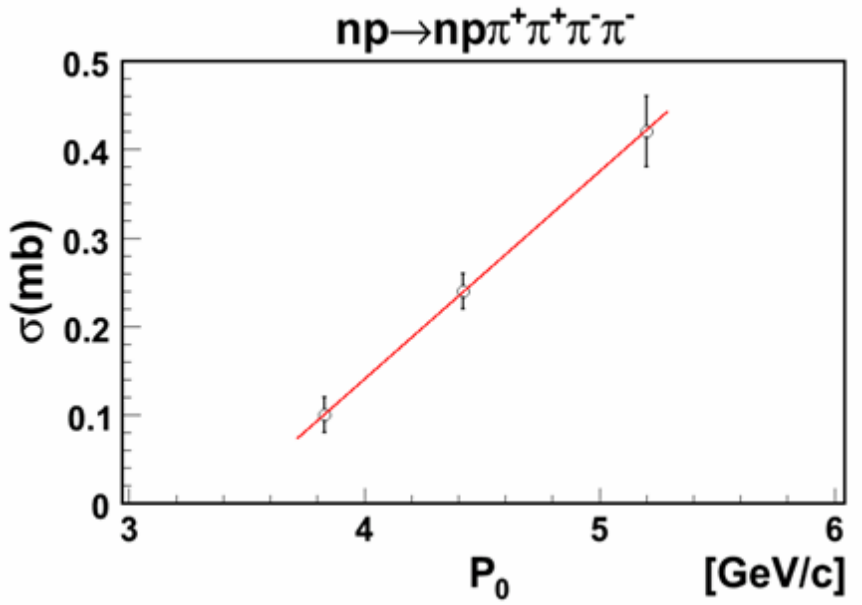


Contributions of η and ω mesons at P_0=5.20 GeV/c :

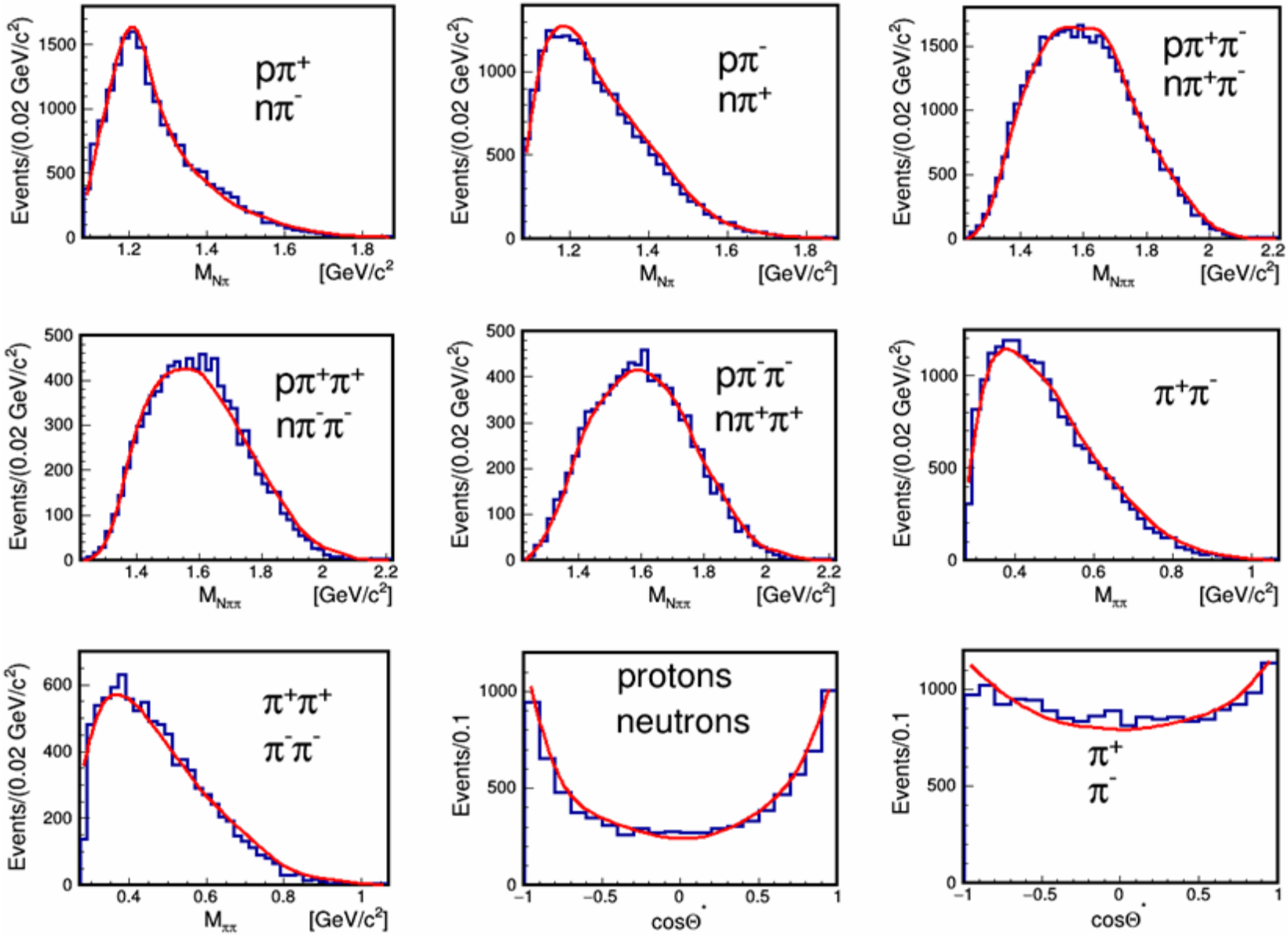
σ_η=(13 ± 2) μb σ_ω=(18 ± 3) μb

- **Reaction** $np \rightarrow np\,\pi^+\pi^+\pi^-\pi^-$

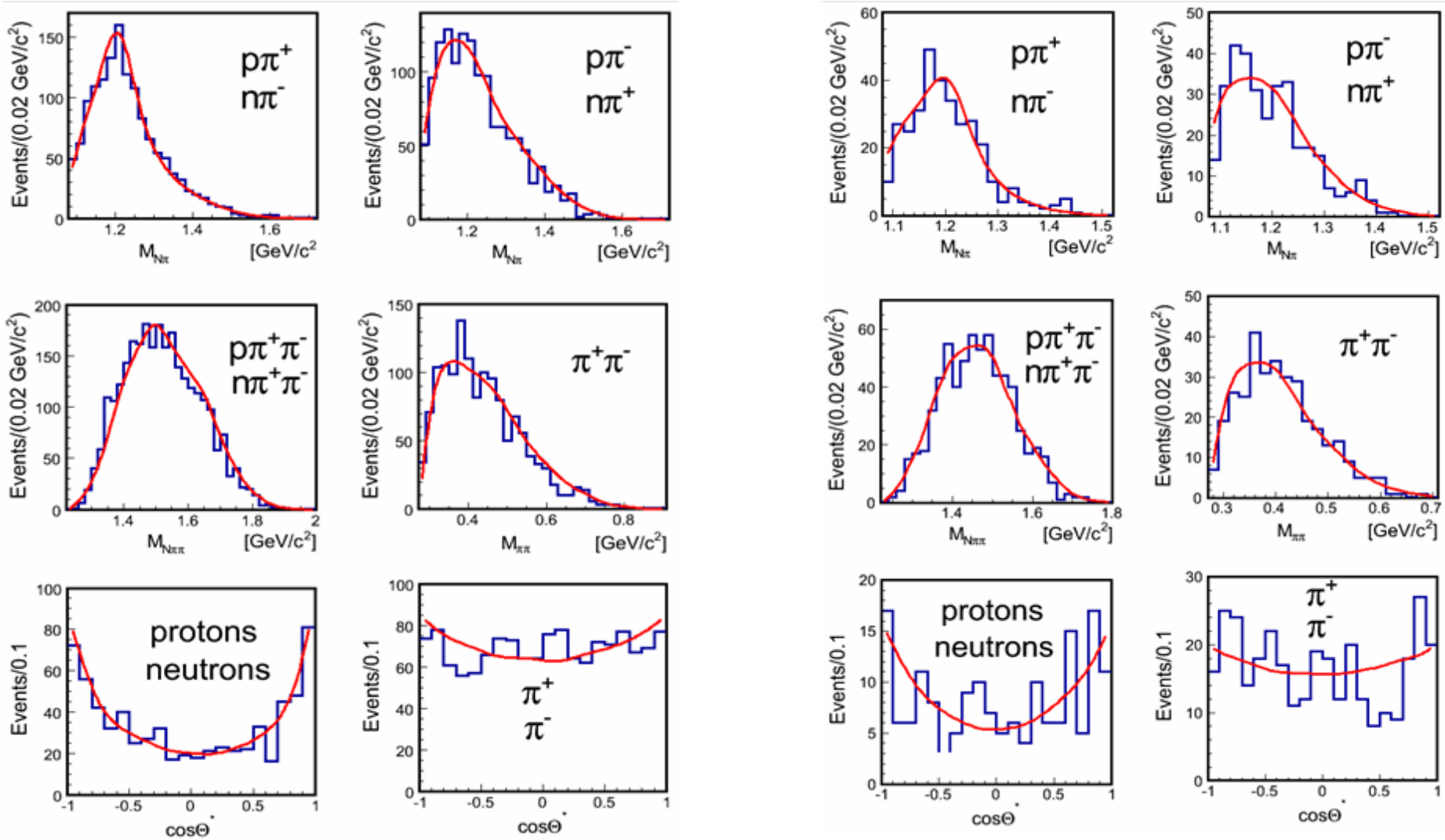




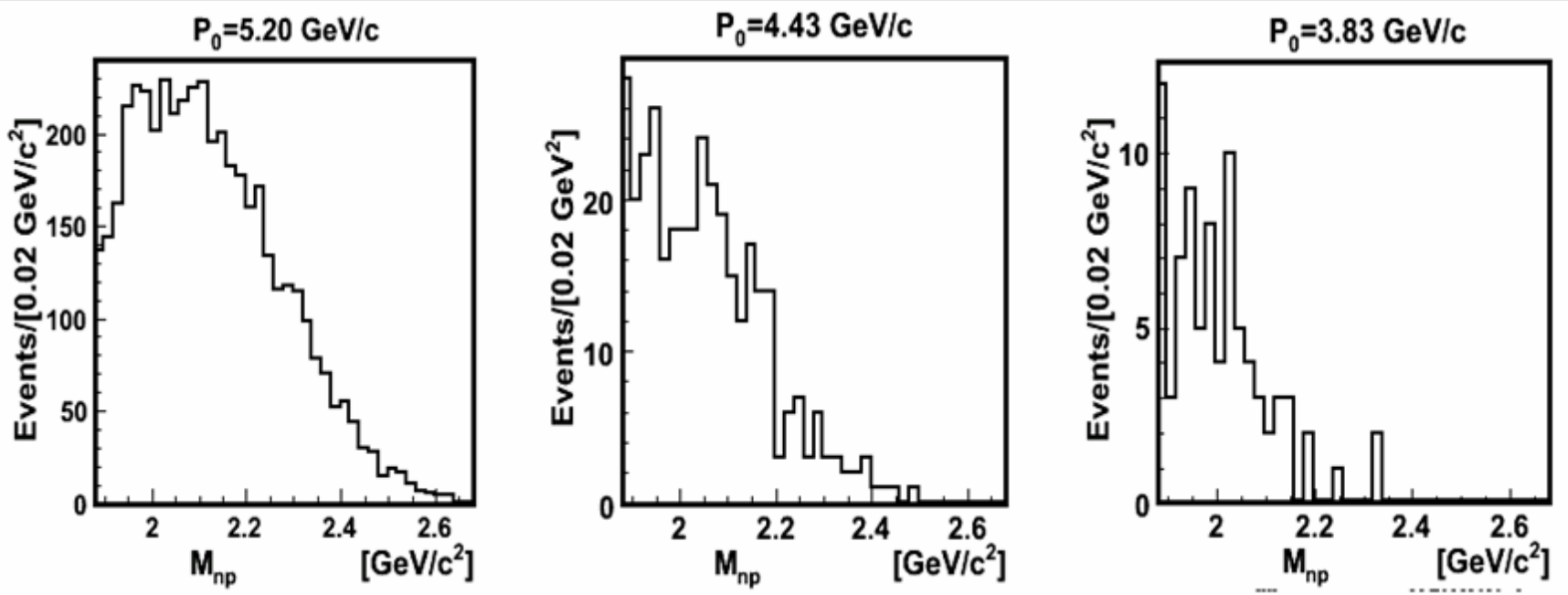
Cross-section of the reaction $np \rightarrow np\,\pi^+\pi^+\pi^-\pi^-$ vs momentum of incident beam.



The distributions for the reaction *np* → *np* $\pi^+\pi^+\pi^-\pi^-$ at P_0=5.20 GeV/c.
Red line – calculations using OPER-model.



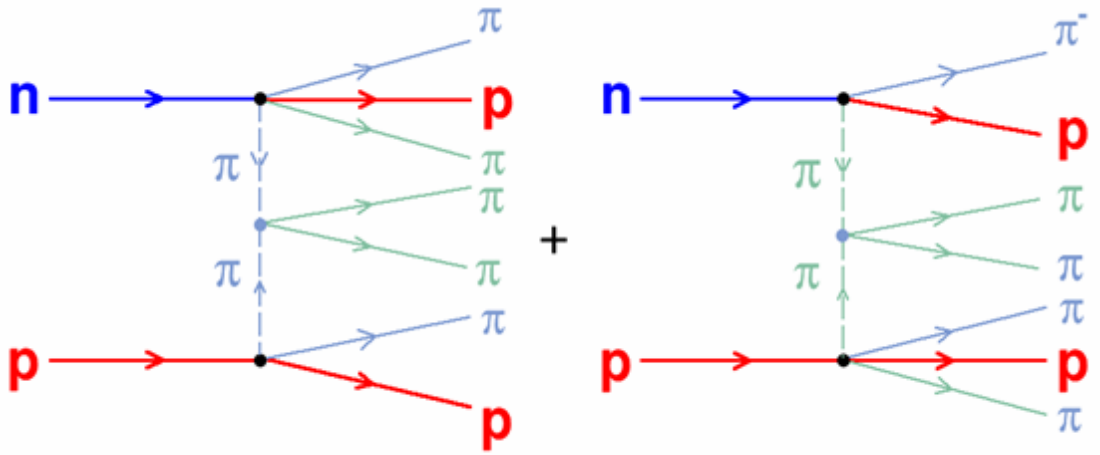
The distributions for the reaction *np* → *np* $\pi^+\pi^+\pi^-\pi^-$ at P_0=4.42 GeV/c (left panel) and at P_0=3.83 GeV/c (right panel). Red line – calculations using OPER-model.



The distributions for the reaction $np \rightarrow np\ \pi^+\pi^+\pi^-\pi^-$ at P_0=5.20 GeV/c P_0=4.42 GeV/c and at P_0=3.83 GeV/c.

5. 5π and 6π production in np interactions

- **Reaction** $np \rightarrow pp\pi^+\pi^+\pi^-\pi^-\pi^-$



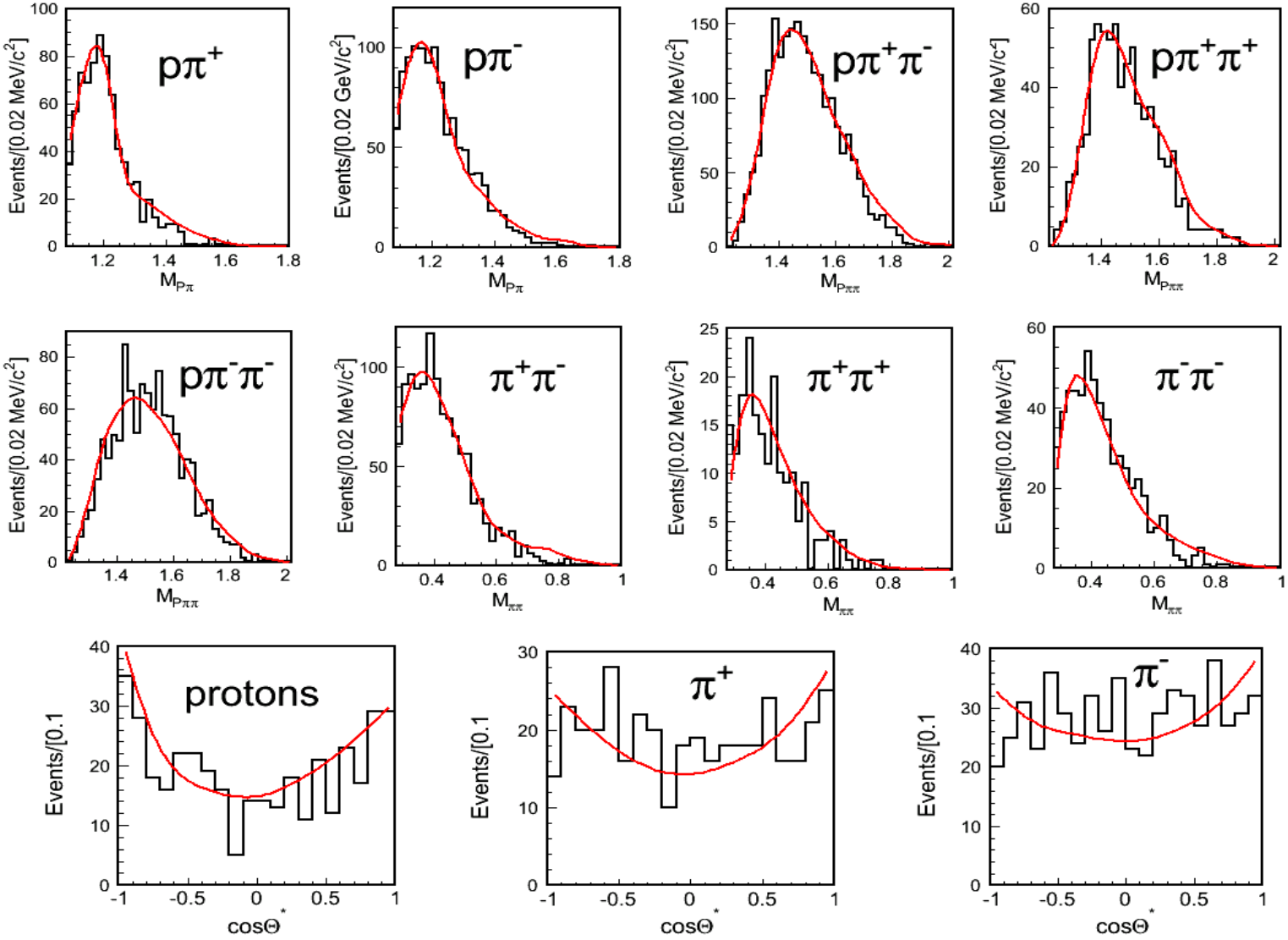
diagrams for the reaction $pp \rightarrow pp\ \pi^+\pi^+\pi^-\pi^-\ \pi^-$

Cross-section for the reactions at P_0=5.20 GeV/c :

$pp \rightarrow pp\ \pi^+\pi^+\pi^-\pi^-\ \pi^-$ $\quad \sigma$ = (18.7 ± 4.1) μb

$pp \rightarrow pp\ \pi^+\pi^+\pi^-\pi^-\ \pi^-\ \pi^0$ $\quad \sigma$ = (3.6 ± 1.0) μb

$pp \rightarrow np\ \pi^+\ \pi^+\ \pi^+\pi^-\pi^-\ \pi^-$ $\quad \sigma$ = (3.7 ± 1.0) μb



The distributions for the reaction *np* → *pp* $\pi^+\pi^+\pi^-\pi^-\pi^-$ at P_0=5.20 GeV/c.
Red line – calculations using OPER-model.

6. Conclusion

- **Multi π-mesons production in *np*-interaction is provided by the excitation and decay of Δ^* and N^* - resonances** (taken from **PWA** and **GIM**).

- **The large peripherality of the secondary hadrons leads to the idea to use some exchange models (π, *P* etc. exchange).**

- **It was shown that there are no noticeable signal of ρ-meson production in the considered reactions .**

- **OPER – model permits to get a good description of the characteristics from 2 up to 6 pions production in np interactions. At lower energies ($P_0 < 3$ GeV/c) it is necessary to take into account another mechanism of the reactions (such as OBE-model).**

P.S. **(OPER+OBE) – model can be used as an effective tool to simulate various reactions of hadron interactions: NICA project, HADES set-up, intranuclear interactions (hA and AA) …**

Thank You for attention !

Reference

- **Experiment and data processing**

1. A.P.Gasparian et al. Prib.Tekh.Eksp., 77, N2 (1977), pp. 37-42.
2. C.Besliu et al. YaF 43 (1986), pp. 888-892.

- **OPER-model**

3. *L.Ponomarev*. **Part. and Nucl.**, v.7(1), pp. 186-248, 1976, JINR, Dubna (in russian).
4. *A.P.Jerusalimov et al*. Study of the Reaction **np** → **np**π^+ π^- at Intermediate Energies. http://arxiv.org/pdf/1102.1574.pdf
5. *A.P.Jerusalimov et al*. Analysis of the Reaction **np** → **np**π^+ π^- from the point of view of The OPER-model. http://arxiv.org/pdf/1203.3330.pdf
6. *A.P.Jerusalimov*. Contribution of the 'hanged' diagrams into the reaction **np** → **np**π^+ π^- at Intermediate Energies. http://arxiv.org/pdf/1208.3982v1.pdf

- **OBE-model**

7. *A.B. Kaydalov and A.F. Nilov*. **YaF**, v.41(3),pp. 768-776, 1985 ; **YaF**, v.52(6), pp. 1683-1696, 1990.
8. NN and ND interactions - a compilation. **UCRL**-20000 NN, august 1970.
9. *V.Barashenkov and B.Kostenko*. JINR Comm. 4-84-761, 1984, JINR, Dubna. (in russian).

- **Other models**

10. L. Alvarez-Ruso, E. Oset, E. Hernandez. NP A633, 519 (1998).
11. Xu Cao, Bing-Song Zou and Hu-Shan Xu. PR C81, 065201 (2010).